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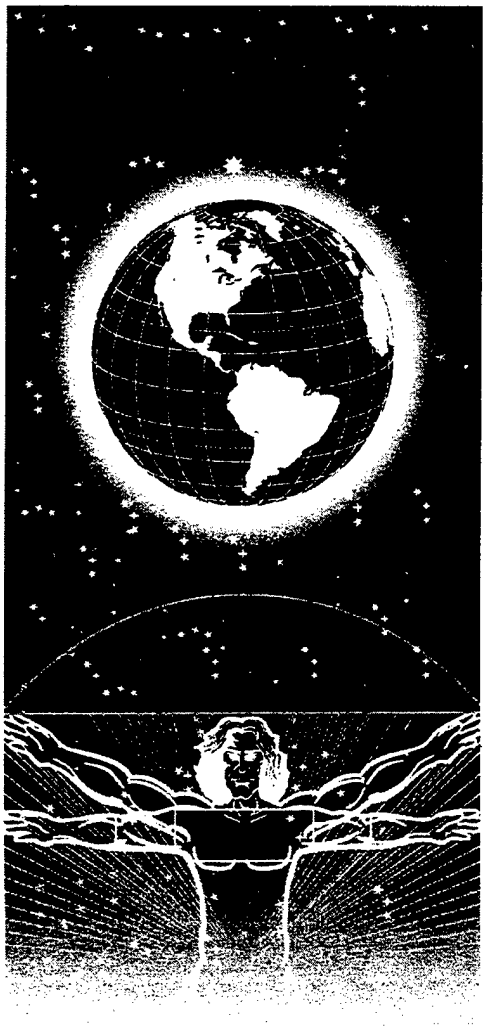

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Radiological Scoping and Characterization Surveys Workplan, 1963 Igloo 572 Accident (Former Medina Base) Lackland Training Annex, Lackland Air Force Base, Texas

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December 2000

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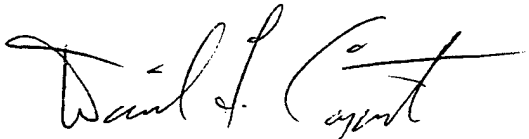

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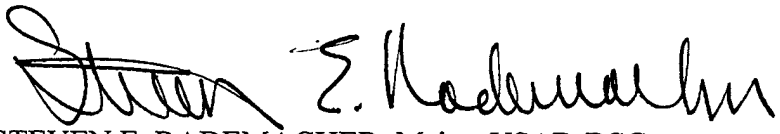

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On 13 Nov 63, 50,500 kg of chemical high explosives detonated and destroyed igloo 572 on Medina Base Texas (now Lackland Training Annex, Lackland AFB TX). The result of the blast was a complete vaporization of the igloo contents, a sizeable crater, and removal of some rock strata below the igloo. The contents of adjacent igloos were not impacted. Fortunately, site personnel received no serious personal injuries. The only known radioactive material dispersed as a result of the explosion was uranium metal that was comprised of both depleted and natural isotopic compositions. Fissile materials were not involved in the accident. Radiation surveys on-site and downwind from the site were accomplished immediately after the accident by Atomic Energy Commission personnel, other Federal government assets, and State of Texas radiation surveillance teams. The results of these surveys concluded that off-site areas were not impacted, however, on-site areas contained elevated uranium concentrations in soils. The highest activity concentration among on-site soil samples was 900 pCi/g of uranium. In May 2000, AFIERA performed a pilot scoping survey of the area with gamma radiation detection equipment, collection, and analysis of the soils for uranium and other radiological constituents. The results of this analysis indicated the presence of uranium in excess of background. The report contains description of proposed scoping and characterization survey work to be accomplished to further define the contamination zone and potentially provide final status conditions if remediation is not deemed necessary. The surveys follow the recommended approach of the Multi-Agency Radiation Survey and Site Investigation Manual.

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Table of Contents

Report Documentation i
Table of Contents iii
List of Figures iv
List of Tables v
1. Introduction 1
    a. Purpose
    b. Site Description
    c. Summary of Proposed Action
2. Historical Site Assessment 2
    a. Historical Record of Accident
    b. EG&G Special Aerial Radiometric Survey
    c. Mason Hanger – Silas Mason Co., Inc. and Sandia Corporation
    d. Texas State Department of Health and Public Health Service
    e. Summary
3. Contaminants of Concern 4
    a. General
    b. Quantification
    c. Background Uranium
    d. Isotopic Mixture of Uranium
4. AFIERA Pilot Scoping Survey 6
5. Health Hazards Risk Evaluation, Regulatory Authority, and Preliminary Remediation Goals . . 6
    a. General
    b. Regulatory Authority
    c. Preliminary Remediation Goals (PRGs)
6. Methodology 9
    a. MARSSIM Approach
    b. Site Survey Methodology
    c. Scoping Survey
    d. Characterization Survey

e. Survey Personnel

f. Instrumentation and Analytical Methods

7. Quality Assurance/Quality Control 16

a. General

b. Private Laboratory Samples

c. Data Analysis of Quality Control Samples

8. Health and Safety 17

a. Radiation Exposure

b. Physical Hazards

c. Adverse Weather Conditions

d. Medical Emergencies

9. References 18

Appendix A - Site Maps of Lackland Training Annex and May 2000 Scoping Survey Soil Sampling Locations 21

Appendix B - Historical Site Investigation Data 27

Appendix C - Uranium Decay Series 35

Appendix D - Uranium Isotopic Distributions 39

Appendix E - RESRAD Calculations 45

List of Figures

1 Scoping Survey Approach 11

2 Sub-Sampling Method 12

3 Grid Pattern Over Contaminated Area 14

A-1 Lackland Training Annex and Vicinity 23

A-2 Lackland Training Annex 24

A-3 May 2000 AFIERA Scoping Survey Soil Sampling Locations. 25

B-1 Aeroradioactivity Map of Medina Base [Figure 1 of EG&G Report] 29

B-2 Aeroradioactivity Map of Medina Base and Vicinity [Figure 2 of EG&G Report] 30

B-3 Aeroradioactivity Map of Medina Base and Vicinity [Figure 5 of EG&G Report] 34

D-1 U-238/U-234 and U-238/U-235 Ratio for Various Concentrations of Depleted Uranium (DU) Contaminant in Presence of 1 pCi/g Background Natural Uranium 41

D-2 U-238/U-234 Ratio for Various Mixtures of Depleted Uranium (DU) and Tuballoy (TU) Contaminant in Presence of 1 pCi/g Background Natural Uranium 42

D-3 U-238/U-234 Ratio for Two Mixtures of Depleted Uranium (DU) and Tuballoy (TU) Contaminant in Presence of Varying Natural Uranium Background 43

List of Tables

1 Characteristics of Natural Uranium (TU) and Depleted Uranium Metals 5

2 γ-Spectroscopy Results for May 2000 AFIERA Scoping Survey Soil Samples 7

3 Survey and Regulatory Personnel 15

4 Instrumentation and Analytical Methods 16

B-1 Atomic Energy Commission On-Site Soil Sampling Analysis Results 31

B-2 Atomic Energy Commission Off-Site Environmental Sampling Analysis Results 32

B-3 Texas State Dept. of Health Environmental Sampling Results 33

C-1 U-238 Decay Series 37

C-2 U-235 Decay Series 38

D RESRAD Calculations 47

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1. Introduction

a. Purpose. This report presents a radiological scoping and characterization workplan for evaluation of residual radioactive materials in soils resulting from an accidental detonation of chemical high explosives (HE) on November 13, 1963. The explosion occurred in igloo number 572 at the Medina Facility on Medina Base, San Antonio TX. The work described in the plan is to be accomplished by the Radiation Surveillance Division of the Air Force Institute for Environment, Safety, and Occupational Health Risk Analysis (AFIERA/SDR) for the Environmental Management Division of the Civil Engineering Squadron (59 CES/CEV), Lackland AFB TX. The workplan generally follows the recommendations of the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NRC 1997). While designed for scoping and characterization, it is flexible to allow a greater effort at the request of the 59 CES/CEV. Practically, this allows the characterization to fulfill a final status survey need if deemed appropriate with the data available.

b. Site Description. During the accident, Medina Base was a separate military installation on the southwest side of San Antonio. The Medina Facility on base was operated by Mason Hanger – Silas Mason Co., Inc. for the Atomic Energy Commission (AEC), Albuquerque Operations' San Antonio Area Office (AEC undated). The only known radioactive contaminant released from the accident was uranium (EG&G 1964). The AEC ceased management of the operation in 1965. The site is currently under control of Lackland AFB and is called the Lackland Training Annex. Igloos on the site are still being used for storage. Appendix A contains maps of the Annex and local area.

c. Summary of Proposed Actions. AFIERA will implement a variety of measurement techniques to assess residual uranium contaminants on the site as a result of the accident. Soil samples will be collected to:

1) assess contaminant concentrations in soils,

2) reference the response characteristics of portable and land vehicle supported in-situ detection systems to the uranium contaminant,

3) estimate the activity concentrations and variability in naturally occurring radioactive materials in unimpacted soils from the area,

4) estimate the isotopic composition of the uranium contamination,

5) assess the quality of the data to support potential remediation or site closure, and

6) provide input data to computer-based, risk-modeling software.

Two laboratory methods will be used for analysis of soil samples: γ- and α-spectroscopy. Two types of field instruments will be used for in-situ γ-measurements: a large-area plastic scintillator mounted on the rear of a six-wheeled gasoline-fueled cart and a 3 inch-by- 3 inch thallium-drifted sodium iodide scintillator [3 x 3 NaI(Tl)]. Risk calculations will be made with RESRAD Version

5.82, a computer-based, risk-modeling software developed by Argonne National Laboratory (Yu *etal* 1993). Recommended actions will be based on comparison of site conditions to risk calculations and the as low as is reasonably achievable (ALARA) principle.

d. Regulatory Involvement. Actions on the site should be coordinated with State of Texas regulatory authorities and Headquarters, Air Force Safety Center (HQ AFSC) at Kirtland AFB NM.

2. Historical Site Assessment

a. Historical Record of Accident.

At approximately 10:24 a.m. (CST) Wednesday, 13 November 1963, 50,500 kg of chemical HE detonated and destroyed Igloo 572. The igloo doors (that opened to a west by southwest direction) were blown from the facility in the initial stages of the blast. The final result of the blast was a complete vaporization of the igloo contents, a sizeable crater, and removal of some rock strata below the igloo (AEC undated). Off-site, windows in buildings several miles from the igloo were broken. Three handling crew personnel, moving HE materials to the interior of the igloo from an outside location, were believed to have initiated the accident (AEC undated). The cause of the accident was never identified, but speculated to be the result of an accidental mechanical contact between two HE components. Fortunately, site personnel received no serious personal injuries. The contents of adjacent igloos were not impacted.

The only known radioactive material dispersed as a result of the explosion was uranium metal (Davis 1963). Two types of uranium metal were involved in the accident: tuballoy (manufactured through separation of uranium from ore) and depleted (uranium depleted in its content of the ^{235}U and ^{234}U isotopes) (EG&G 1964). The fraction of depleted uranium (DU) and tuballoy (TU) was not available for preparation of this report. Fissile materials (i.e., weapons grade plutonium (WGP) and highly enriched uranium) were not involved in the accident.

Radiation surveys on-site and downwind from the site were accomplished immediately after the accident by Medina Facility personnel and an Air Force helicopter/Sandia Corporation team (AEC undated). Using portable α- and β/γ-radiation survey instruments, no α-radiation count rates or γ-radiation exposure rates were measured above that typical of naturally-occurring background sources (Davis 1963). Metallic fragments and unexploded high explosives were not identified as part of the debris (AEC undated). Wind direction and velocity data were obtained from the U.S. Weather Bureau, focusing downwind survey teams in a west by southwest direction to the town of La Coste (Davis 1963). La Coste, 20 miles downrange from the igloo, was specifically targeted for survey because the dust/debris cloud was observed to be quite heavy near the ground (Davis 1963).

Extensive follow-on aerial radiation surveys, soil samples analysis, and ground surveys were performed by Federal, Federal-contract, and State organizations. The results of those evaluations are summarized below.

b. EG&G Special Aerial Radiometric Survey. EG&G's Santa Barbara Laboratory performed aerial measurements at the site the day after the accident (EG&G 1964). A specially designed aircraft with a 23 cm x 7.6 cm NaI(Tl) γ-radiation detector scanned areas over the base and out to more than 25 miles from the site (EG&G 1964). The survey over Medina Base was accomplished at a height of 150 meters above ground level (AGL). The results of the aerial scan of the base are in

Figure B-1 of Appendix B. Numerous lines were flown in the vicinity of Igloo 572 and the base perimeter. A background radiation count rate of about 300 counts per minute (cpm) was recorded, with annotation of the net count rate for each survey line on the figure. Four off-site lines were flown at 150 meters AGL following small country roads between U.S. Highway 90 from the north to U.S. Highway 81 on the south. One parallel route was flown south of U.S. Highway 81. Thirteen one-minute γ-spectra were also recorded at various downwind locations at a height of 60 meters AGL. Figure B-2 contains the survey results, with the lines annotated with net count rates as in Figure B-1, but with the spectra locations circled. While the survey lines had elevated count rates above background levels, EG&G concluded that the pattern of excess count rates was not consistent with a pattern of dust fallout from an accident of this type (EG&G 1964). Evaluation of the spectral data as well appeared consistent with the background (EG&G 1964). EG&G concluded their report with the following statement (EG&G 1964).

> "The state-of-the-art of aerial radiometric instrumentation is more advanced than the state-of-knowledge of environmental radiation. Until more is known about what to expect in the way of pre-accident environmental background (gamma count rate and energy spectra), reports on minor accidents such as this [in radiological terms] will continue to read 'the variations are within the normal range of environmental radiation'."

c. Mason Hanger - Silas Mason Co., Inc. and Sandia Corporation. Mason Hanger - Silas Mason Co., Inc. collected soil and water at both on-site and off-site locations (Kingsley 1963). The samples were analyzed through a combination of chemical extraction and liquid scintillation counting. The results of the analyses are reported in terms of micrograms of ^{238}U, with a calculation of the corresponding ^{238}U activity concentration from the author of this report. The original reference does not have details on the reported activity concentrations of the ^{234}U and ^{235}U. It is speculated that the total contaminant activity concentration (i.e. ^{234}U, ^{235}U, and ^{238}U) was attributed to ^{238}U. Table B-1 contains the results of the samples collected on-site. The activity concentrations ranged from those typical of background soil to over 700 pCi g^{-1}. These sampling results confirm that measurable concentrations of uranium contamination existed at concentrations significantly above background. It is not known if areas of the highest contamination were removed from the site at some time after the accident. Soil sampling depth was not noted in the report. The letter summarizing the sample results had no referenced benchmark of the coordinate system used, rendering this data unusable for follow-on survey work. Table B-2 contains a summary of the off-site sample analysis results. None of the samples had activity concentrations of uranium differentiable from background.

d. Texas State Department of Health and Public Health Service. The Texas State Department of Health collected soils, vegetation, and water samples from off-site areas. The Public Health Service's laboratory in Montgomery Alabama analyzed the samples, with summary results in Table B-3 (Barden 1963). All samples were initially screened though γ-spectroscopy analysis. None of the samples had remarkable γ-ray signatures unexplained by natural background sources (SRHL 1963). The vegetation and soil samples were then ashed and a small aliquot was evaluated for total α-radiation. Water samples were filtered. Filtered media were ashed and evaluated for α-radiation content. The supernatant fraction was evaporated and evaluated for α-radiation content. Only one of the samples had α-radiation concentration deemed remarkable. This vegetation sample, SpV-9, was collected off Masterson Rd. The sample had a α-radiation activity concentration almost eight times the next highest sample. However, the soil sample collected in the same area had

α-radiation levels typical of background samples. The Public Health Service attributed the elevated α-radiation content of this sample to variability in uptake of natural radioactivity in soils (SRHL 1963). Additional sampling in this area was not accomplished.

e. Summary.

In summary, there was extensive sampling of environmental media in both on- and off-site areas. Many factors, however, limit the usefulness of this data today. First, knowledge of background radiation and its variability was limited. Sample analysis methodology (i.e. instruments and methods) was not as extensive and as capable as that today. For example, liquid scintillation analysis was performed to assess uranium activity, while today α-spectroscopy analysis may have been performed or high-resolution γ-spectroscopy with hyperpure germanium solid-state detectors. Lastly, radiation protection standards for individuals in the general public have decreased over the last 40 years. Accidents involving only DU (and TU) were treated differently than accidents involving weapons grade plutonium (WGP). The primary difference in safety concern between the two radioactive materials is related to the specific activity (i.e. activity per mass, with DU at 0.4 $\mu Ci\ g^{-1}$ and the α-radiation emitters of WGP at 70,000 $\mu Ci\ g^{-1}$), but also was related to criticality safety and security of WGP. Furthermore, due to the relatively low specific activity of DU, protection of occupationally exposed individuals to insoluble forms of DU is dictated by heavy metal toxicity rather than radiological.

The soil sampling results collected on-site had some α-radiation activity concentrations significantly higher than background. The area encompassed by the contamination zone is unknown from this sampling data because the coordinate system was not well documented. Due to the high activity concentrations of the soil samples, and uncertainties in the area and depth of sampling, additional investigation is recommended.

3. Contaminants of Concern

a. General.

Based on the historical record, the only contaminants of concern are DU and TU. Uranium, a naturally occurring radioactive element, is silvery-white in its pure form. It is a heavy metal nearly twice as dense as lead (19 $g\ cm^{-3}$). Uranium occurs in nature in a wide variety of solid, liquid, and gaseous compounds. It readily combines with other elements to form uranium oxides, silicates, carbonates, and hydroxides. These compounds range from being highly mobile (soluble) to being relatively immobile (insoluble) in the environment.

Uranium-metal alloys are readily machinable and have metallurgical properties similar to those of high-strength steels. Finely divided uranium metal is pyrophoric (i.e., burns spontaneously in air). Table 1 contains the isotopic composition of TU and DU. Table C-1 of Appendix C provides a partial list of nuclides and their emissions from the ^{238}U decay series. The ^{235}U decay series is listed in Table C-2.

Table 1. Characteristics of Natural Uranium (TU) and Depleted Uranium (DU) Metals.

Uranium Type	Isotopic Mixture			Specific Activity (μCi g^{-1})
	U-234	U-235	U-238	
Mass				
TU	0.0054 %	0.72 %	99.3 %	0.7
DU	0.001 %	0.2 %	99.8 %	0.4
Activity				
TU	48.9 %	2.25 %	48.9 %	0.7
DU	15.3 %	1.06 %	83.6 %	0.4

b. Quantification. ^{234}Th is the most readily quantifiable short-lived daughter of ^{238}U as measured in gamma spectroscopy systems. For gamma spectroscopy measurements of the soils collected from a previous AFIERA characterization study of uranium in soils (Rademacher and Hoak 2000), typical minimal detectable concentrations (MDC) were in the range of 1 pCi g^{-1}. ^{235}U emits a 0.185 MeV γ-ray with a percent yield of 57 %. This nuclide has an MDC about one-tenth that of ^{238}U (Rademacher and Hoak 2000). Some problems are encountered in the evaluation of low-activity concentration samples of ^{235}U. This is due to difficulties in differentiation of the 0.185 MeV γ-ray from ^{235}U and the 0.186 MeV γ-ray from ^{226}Ra, an isotope in natural background. Quantification of ^{234}U activity concentrations in soils is considerably more difficult than either ^{235}U or ^{238}U. A 0.093 MeV γ-ray is the only significant photon emitted and has an emission frequency of 5 %. Evaluation of this photon is confounding due to a 0.092 MeV γ-ray emitted by ^{234}Th. α-spectroscopy analysis is an effective technique for quantification of uranium in soils. It generally is more accurate in determining isotopic mixtures than γ-spectroscopy.

c. Background Uranium. Uranium is naturally occurring in the earth's crust. The isotopic mix is the same as that of TU as listed in Table 1. Activity concentrations of naturally occurring uranium in the earth's crust are highly variable, having some correlation to soil type. The average total uranium concentration in surface soils in the U.S. is about 2 pCi g^{-1} (Myrick 1983). The Department of Energy (Myrick 1983) investigated activity concentrations at former Manhattan Engineering District Sites and early AEC sites, including the San Antonio area. Total uranium activity concentrations ranged from 0.24 to 7.7 pCi g^{-1} among 355 samples analyzed from across the U.S. For Texas (largely the San Antonio area), the values ranged from 0.98 to 3.1 pCi g^{-1}, with a mean and standard deviation of 1.7 and 1.2, respectively. The U.S. Geological Service performed aerial γ-radiation measurements of the San Antonio area in 1956 and are reproduced in Figure B-3 of Appendix B. These measurements are significant because they were collected prior to bulk deposition of fallout from global atmospheric nuclear weapons testing and provide a qualitative representation of natural variability in background radiation for the Lackland Training Annex vicinity.

d. Isotopic Mixture of Uranium.

The isotopic mixture of the uranium impacts radiation-exposure risk calculations and the use of surrogate measurements for in-situ γ-radiation detection instruments and laboratory γ-spectroscopy measurements. Ratios of isotropic constituents of uranium are characteristic of the uranium type.

Figure D-1 contains a plot of the ^{238}U to ^{235}U and ^{238}U to ^{234}U ratios for DU in the presence of a natural-uranium background of 1 pCi g^{-1}. Natural uranium and TU have a ^{238}U to ^{234}U ratio equivalent to one for all activity concentrations. Chemical separation and α-spectroscopy analysis of soil samples in the laboratory can be used to readily assess both ratios. The ratio of ^{238}U to ^{235}U can be readily evaluated by γ-spectroscopy analysis of soil samples in the laboratory, but only for soil samples with activity concentrations sufficiently above background. γ-spectroscopy analysis is not effective in assessment of the ^{238}U to ^{234}U ratio.

Because the relative contribution of DU and TU to the contaminant is not known, soil samples must be evaluated to determine the relative contribution of each. Figure D-2 contains a plot of ^{238}U to ^{234}U ratios for various combinations of DU and TU in the presence of a natural-uranium background of 1 pCi g^{-1}. From the plot, apparent is the drastic change in ratios dependent both on total uranium concentration and contaminant mixture. For low uranium activity concentrations, natural variability in background uranium may confound this analysis. Figure D-3 contains a plot of ^{238}U to ^{234}U ratios for two mixture-fractions of DU and TU and for three different background uranium concentrations. From the plot, discrimination between the two mixtures is confounded by significant variability in background activity concentration. This type of evaluation should be made with samples of uranium activity concentration greater than 10 pCi g^{-1} because variation in background uranium concentrations will have a small influence on total sample isotopic concentrations.

4. AFIERA Pilot Scoping Survey. On 17 May 2000, the Radiation Surveillance Division of AFIERA performed a pilot scoping survey. The survey consisted of measurements with a large-area plastic scintillator mounted on the rear of a six-wheeled gasoline-fueled cart and the collection of four soil samples. Areas of elevated γ-radiation were detected by the plastic scintillation system (results of the scanning survey not presented here). Two soil samples were collected in areas believed to be unimpacted (i.e. background), while two were collected in areas identified by the scanning survey to have elevated γ-radiation levels. The survey locations are annotated on Figure A-3, with the γ-spectroscopy results in Table 2. The two flagged sampling locations had activity concentrations of ^{235}U and ^{238}U significantly elevated above background concentrations. Other reported radionuclide concentrations were typical of background. The ratio of ^{238}U to ^{235}U for the two flagged samples is noted in Table 2. Comparison of the ratios to the plot of Figure D-1 indicates that the samples contain DU, though the ratios are not as high as that expected for a 100 % DU contaminant. Due to the relatively high uncertainty in the estimated ratios, conclusion regarding the exact contaminant composition could not be made from this data.

5. Health Hazards Risk Evaluation, Regulatory Authority, and Preliminary Remediation Goals.

a. General. For low-level radioactive uranium contamination in soils, the primary health hazard concern is long-term exposure to low dose-rate external radiation and internal deposition. The primary health hazard risk from exposures of this type is excess risk of cancer induction, with secondary detriments including life-shortening, genetic effects, etc.

b. Regulatory Authority.

The uranium involved in this accident is categorized under the Atomic Energy Act (AEA) of 1954 as a Section 91b exempt material and is not subject to regulation by the Nuclear Regulatory Commission (NRC). Regulation of the material within the Department of Defense (DoD) is

Table 2. γ–Spectroscopy Results for May 2000 AFIERA Scoping Survey Soil Samples.

Sample Number	10000475	10000476	10000477	10000478
Sample Location	Flag 8	Flag 9	Background 1	Background 2
Isotope	Activity Concentration (pCi g^{-1}) *			
U-235	0.90 ± 0.14	1.4 ± 0.2	< 0.12	< 0.11
Th-234	37 ± 4	55 ± 6	< 1.3	< 1.3
Ra-226	< 2.9	< 3.3	3.9 ± 1.5	< 1.9
Pb-214	0.4 ± 0.2	0.31 ± 0.17	0.6 ± 0.2	0.51 ± 0.15
Bi-214	0.5 ± 0.2	0.50 ± 0.13	0.65 ± 0.17	0.58 ± 0.23
Th-232	0.4 ± 0.3	0.7 ± 0.4	0.7 ± 0.3	0.6 ± 0.3
Pb-212	0.76 ± 0.15	0.71 ± 0.19	0.45 ± 0.14	0.86 ± 0.18
Bi-212	< 0.67	< 0.70	< 0.67	< 0.64
Cs-137	0.19 ± 0.09	0.17 ± 0.08	0.23 ± 0.07	0.11 ± 0.05
Nb-95	0.24 ± 0.13	0.40 ± 0.12	NR	NR
$\frac{\text{U-238}}{\text{U-235}}$	41 ± 8	39 ± 7	I	I

* Uncertainty Levels at the 95 % Confidence Level NR = Not Reported I = Incalculable

delegated to the Commander of the Air Force Safety Center (HQ AFSC) (see Air Force Instruction 40-201, *Managing Radioactive Materials in the Air Force*). For unrestricted public release of former radioactive material use facilities, HQ AFSC follows industry-accepted standards, guidelines, and applicable environmental regulations under the Federal Facilities Compliance Act of 1992. Under the AEA and Reorganization Plan No. 3 of 1970, the Environmental Protection Agency (EPA) is authorized to issue Federal guidance on radiation protection matters as deemed necessary by the Agency or as mandated by Congress. This authority may be delegated to the States.

The NRC sets limits for the unrestricted release of sites with residual licensed radioactive materials. Generic site release criteria are based on an allowable dose equivalent of 25 mrem yr^{-1} above background from residual radioactive contamination and the as low as is reasonably achievable (ALARA) principle. The EPA proposed a draft rule for allowable dose equivalent from residual radioactive materials. The criteria included a 15 mrem yr^{-1} above background limit and the ALARA principle. Though a draft rule, the 15 mrem yr^{-1} above background limit has been applied to the remediation of many sites.

c. Preliminary Remediation Goals (PRGs).

1) General. Estimates of exposure to individuals from residual radioactive materials in soils is a complex issue that is dependent on many factors to include contaminant concentrations, depth distribution of the contaminant, size of the contaminated area, chemical properties of the contaminant and soils, land use, occupancy, and many others. Generally, land areas designated for unrestricted public use are more restricted in allowable residual radioactive materials compared to industrial sites. Though this site is not planned for unrestricted public release, it is generally prudent

to consider long-term use scenarios if remediation efforts are planned. As such, for brevity, this document only considers this scenario.

2) Computer Calculated Risk Assessment.

RESRAD (Yu *etal* 1993) is a computer code specially designed to model radiation exposure to individuals from radioactive materials in environmental media. The computer code is widely accepted in the radiation protection industry and by Federal regulatory bodies and many States. Appendix E contains a tabular summary of RESRAD calculations performed for DU and TU contaminants with variable land area and contaminated zone thickness; all other parameters were set to the default for the code. The table contains dose conversion guideline values (DCGL's) based on a residual dose-equivalent rate of 15 mrem yr^{-1}. $DCGL_W$ values are those applied for residual radioactivity that is evenly distributed over a large area as defined in the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NRC 1997). The DCGLs have not been negotiated among the State of Texas or HQ AFSC. For this report, these values represent PRGs that will aid the 59 CES/CEV and AFIERA in directing field activities.

The first six-rows of data in the table were calculated for a DU contaminant with varying contamination zone thickness. The 10,000 m^2 area used for these calculations is the default area used in RESRAD. The dose equivalent rate is nearly inversely proportional to the contamination zone thickness.

The only difference between rows 6 and 7 is the uranium contaminant type. For a two-meter contamination zone thickness, the difference between a DU and TU contaminant in calculated dose-equivalent rate is only 20 %. For rows 8 and 9, the contamination zone thickness used was 0.15 m with respective TU and DU contaminants. For the two cases, the DU contaminant is about 20 % lower in projected dose-equivalent rate.

Cases 9, 10, and 11 illustrate the effect of contamination zone area on dose-equivalent rate for a DU contaminated zone 0.15 m thick. For a 100 m^2 contamination zone, the dose-equivalent rate is 60 % of that of the default area. Subsequent case groupings (12, 13, 14, and 15) and (16, 17, 18, and 19) illustrate the effect of contamination zone area on dose-equivalent rate for 1 and 2 m thick contamination zones, respectively. The reduction in dose-equivalent rate from the default of 10,000 m^2 to 100 m^2, demonstrates the same trend as the 0.15 m thick contamination zone case, but to a much greater degree. The cases with areas less than the default are provided to illustrate projected doses from areas of elevated contamination commonly called "hot spots." In the MARSSIM approach (NRC 1997), "hot spots" are compared to special elevated measurement DCGLs ($DCGL_{EMC}$).

3) PRG Summary. The lowest DCGL level predicted from RESRAD runs listed in Table E (15 pCi g^{-1}) applies to a contamination zone of 10,000 m^2, with a two-meter thick DU contaminant. The highest DCGL level predicted from RESRAD runs listed in Table E (251 pCi g^{-1}) applies to a contamination zone of 100 m^2, with a 0.15 m thick DU contaminant. These two extreme cases represent a reasonable preliminary boundary of DCGLs that could be applied based on a 15 mrem yr^{-1} dose equivalent rate limit. The area and thickness of the contamination zone could significantly effect a final DCGL for the site. The contaminant type has a minor effect, but must be known if γ-spectroscopy analysis will be used for analysis of soil samples.

6. Methodology.

a. MARSSIM Approach. MARSSIM is a document that provides information on planning, conducting, evaluating, and documenting building surface and surface-soil final-status radiological surveys for demonstrating compliance with risk-based regulations and standards. The document represents a consensus among the Department of Energy, Department of Defense, Environmental Protection Agency, and Nuclear Regulatory Commission. Investigations described in this report generally follow the recommendations of MARSSIM. Overall MARSSIM recommends the following steps in site investigations:

1) historical site assessment (already contained in this document),

2) scoping survey process (primary focus of this document),

3) characterization survey (secondary focus of this document),

4) remedial action support survey (beyond the scope of this document), and

5) final status survey (secondary focus of this document if remediation is not accomplished).

Throughout the process described above, data quality indices are carried over to successive steps in the process. Some of these indices listed later in this report are based on AFIERA previous experiences with DU contaminants and AFIERA laboratory analyses. Overall, this process maximizes the value of data, minimizes soil sampling and survey requirements, and reduces the potential for resampling, while meeting the objective of adequately quantifying contaminant concentrations and locations.

b. Site Survey Methodology. Site survey methods will be comprised of in-situ measurements with portable and vehicular portable instruments in the field, and soil-sampling analyses performed in the laboratory. Two distinct field survey stages are planned: a scoping survey and a characterization survey.

c. Scoping Survey.

1) Unimpacted Area. Figure 1 contains the approach for the scoping survey. The first step in the process is the selection of an impacted area near Igloo 572 at sufficient distance and upwind of Igloo 572 for meteorological conditions that existed during the accident. At each of the 15 locations in the unimpacted area, paired measurements will be collected with the plastic scintillator and the 3 x 3 NaI(Tl). Also, at these locations, surface soil samples will be collected from the top 15 cm. All of the soil samples will be analyzed by γ-spectroscopy, with five having α–spectroscopy analysis for uranium isotopes. The sampling data will be analyzed to determine mean and variability in instrument response, and correlation between the two instruments. The distribution of naturally-occurring radioactive constituents of soil will be assessed.

2) Plastic Scintillator Scanning Measurements.

The impacted area surrounding Igloo 572 will be scanned with the plastic scintillator that is mounted on a gas-powered land vehicle. The instrument output response will be archived by a computerized

data logging system that simultaneously records vehicle location from a geographical positioning system (GPS) located on the vehicle.

Circular scans about the igloo will be performed at 30 m increments. The data from each circular scan will be compared to the standard deviation and mean count rate from the unimpacted area. Locations on the circle exhibiting count rates in excess of three standard deviations above mean background will be flagged for further investigation. To ensure locations are not flagged based on variability in background count rates, an adjacent measurement must be elevated. After six circular measurement patterns, successive patterns will have measurements only between those angles having flagged measurements from previous circular patterns. Circular scanning patterns will be ceased at the site boundary or once flagged measurements are no longer observed.

Areas flagged for elevated measurements from the circular scanning survey will be scanned in a finer grid-pattern. The spacing of the grid will be dependent on the size of the area flagged and variations in measurements along the circular lines. For large areas, a fine grid pattern would require a long survey time, with little value added for a scoping survey. High variability among closely spaced survey points would be indicative of localized "hot spots." Discovery of these locations may require closely spaced grid-patterns.

3) Soil Sampling and Fixed In-Situ Measurements. About 40 locations will be selected for soil sampling based on the results of the scanning survey measurements. Soil sampling locations will be stratified to include a selection of points in areas of highly, slightly, and unelevated scanned measurements. Measurements with the 3 x 3 NaI(Tl) and plastic scintillator will be made prior to soil sampling. Fifteen locations with elevated scanning measurements will have stratified soil sampling at 0 – 5, 5 – 10, 10 – 15, 15 – 30, and 30 – 45 cm below the surface. The other locations will be sampled at a 0 – 15 cm depth. To reduce the effect of heterogeneity, samples will be composited from sub-samples as shown by Figure 2. Sampling in the top 15 cm will be accomplished with a stainless steel trowel. Between successive 5 cm lifts, the trowel will be cleaned with distilled water. Greater depths will be collected with a manual split-spoon sampler. The sampler will be cleaned with distilled water between lifts. The soil samples will be containerized in one-gallon screw-top plastic jars or double-wrapped plastic bags. The sample containers will be wiped with a damp cloth prior to packaging to remove exterior contamination. The container lids will be sealed with tape and packaged in partitioned cardboard boxes. Chain of custody will be documented on a chain of custody form and specific sample data will be collected on an AF Form 2753, *Radiological Sampling Data*. To maintain chain of custody, all samples will be under constant observation, or secured. All sample labels will be completed using waterproof ink.

4) Laboratory Sample Analysis. All soil samples prepared for laboratory analysis will be dried in an oven at 100 °C for 24 hours. The samples will be blended and homogenized. Approximately 500 g will be analyzed by high-resolution γ-spectroscopy. Analysis of the ^{235}U and ^{238}U activity concentrations will be made. About 15 samples, with elevated uranium-activity concentrations, will be selected for α-spectroscopy analysis. To evaluate the variability in the analysis technique, five samples will have multiple aliquot analysis. Isotopic ratios will be evaluated to assess the uranium mixture characteristics.

Figure 1. Scoping Survey Approach.

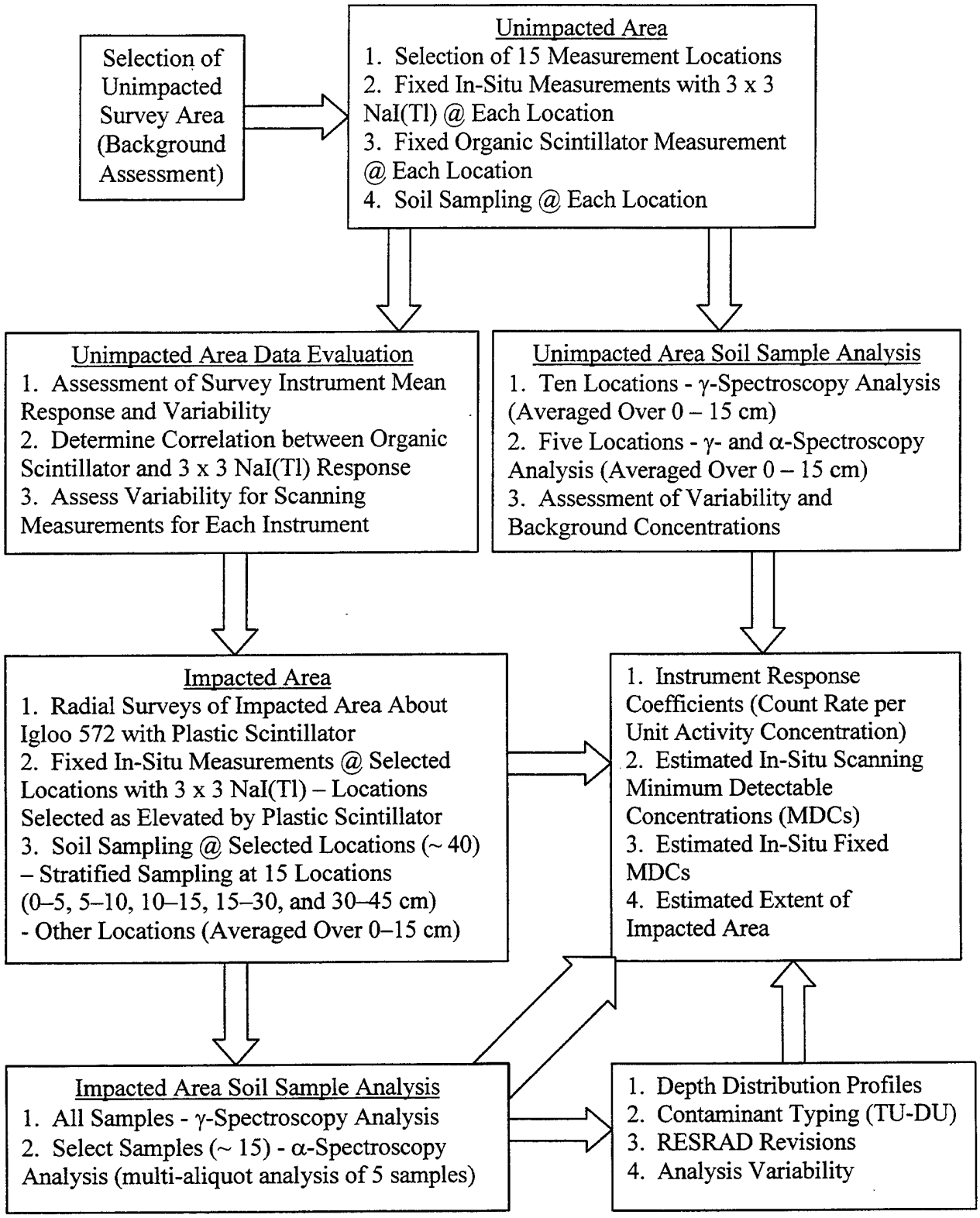
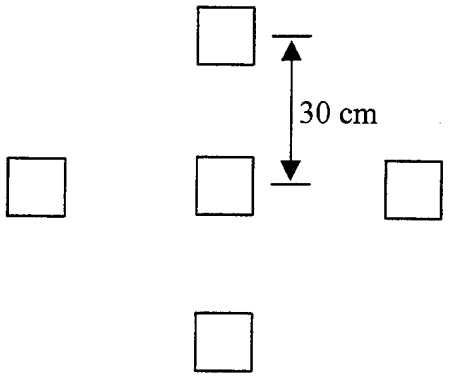


Figure 2. Sub-Sampling Method.



d. Characterization Survey.

1) General. The characterization survey may be a minor expansion of the scoping survey or a significantly more detailed survey dependent on the results of the scoping survey. If the scoping survey indicates that remediation may be likely, then the primary focus of the survey would be to further define the contaminated areas. However, if the results of the scoping survey indicate that remediation may not likely be required, then the characterization survey would likely be expanded to fulfill the requirements of a final status survey. The two methods of survey consist of in-situ scanning measurements and direct measurements. Direct measurements are comprised of fixed in-situ γ-measurements and soil sampling. Minimal detectable concentrations (MDCs) for fixed in-situ measurements can be inferred from correlation of fixed in-situ measurements and soil sampling results from the scoping survey. Previous experience with DU surface contamination in soils demonstrated that the MDC for a 3 x 3 NaI(Tl) is less than 10 pCi g^{-1} (Rademacher 2000). Scanning in-situ γ-measurements with the plastic scintillator will assist in the identification/discounting of "hot spot" areas. The scanning MDC for this instrument can be inferred by comparing the response of the instrument to paired soil sampling results from the scoping survey and Equation 6-10 of MARSSIM (NRC 1997).

2) Classification of Survey Areas. Data collected from the scoping survey in conjunction with historical information presented in this report will be evaluated to classify survey areas for potential for containing contaminated material. Per the definitions in MARSSIM (NRC 1997):

a) class 1 areas are those previously subjected to remedial actions, had known leaks of spills, were former burial sites, waste storage sites, and contained solid pieces of material with high specific activity;

b) class 2 areas are similar to class 1 areas, but are not expected to contain contamination in excess of the $DCGL_W$; and

c) class 3 areas are impacted areas with contamination expected to be a small fraction of the $DCGL_W$.

From scoping data and the historical record, it is clear that some areas have activity concentrations of uranium above the lowest PRG (preliminary $DCGL_W$) of 15 pCi g^{-1} for DU. The purpose of classifying survey areas is to direct the greatest survey effort to those areas with the greatest potential for contamination. Once areas are classified, survey units can be designated. MARSSIM recommends the following land area sizes: up to 2,000 m^2, 2,000 to 10,000 m^2, and unlimited, respectively for class 1, 2, and 3 survey units.

3) Direct Measurements.

a) General. Direct measurements for the characterization survey will be comprised of fixed in-situ γ-measurements and soil sample analysis. In-situ γ-measurements are more cost effective than soil sample collection and subsequent laboratory analysis. Direct measurements will be incorporated into the characterization survey regardless of whether or not remediation is deemed necessary from the results of the scoping survey. The number and balance of soil samples and fixed in-situ measurements are dependent on the intent of the survey. In the event a survey unit is to be sampled for the purpose of remediation, the number and balance will be largely judgmental, with primarily fixed in-situ measurements. For survey units not intended for remediation, all direct measurements will be comprised of fixed in-situ γ-measurements with a 3 x 3 NaI(Tl), and a set fraction of those measurements paired with soil samples. The paired direct measurements will be accomplished to demonstrate agreement between the two techniques. The number of soil samples selected for survey units will be judgmental. For planning purposes, 10 – 25 % of the direct measurement points will have soil sample collection. The percent selected for each survey unit will be based on the correlation between the two measurement techniques from the scoping survey and the number of direct measurement locations in a given survey unit. A minimum of 10 soil samples will be collected per survey unit, with the maximum number expected to be less than 25. The following discussion provides the basis for determination of the number of direct measurements required for the Wilcoxon Rank Sum (WRS) as used in the final status determination. The approach generally follows the recommendations of MARSSIM (NRC 97).

b) Final Status Survey. There are numerous factors incorporated into determination of the number of direct measurement points required in a final status survey. Among them the most significant for this project involving mixed DU and TU contaminants are the target Type I (α) and Type II (β) decision error values, the lower bound of the gray region (LBGR), the $DCGL_W$, $DCGL_{EMC}$, the standard deviation of the contaminant (σ), and area factor. By recommendation of MARSSIM (NRC 1997), the Wilcoxon Rank Sum test will be used to verify compliance with the $DCGL_W$.

c) Decision Error Values. Both decision error values, α and β, will be set at 0.05 for planning purposes.

d) DCGLs, LBGR, and Area Factor. A $DCGL_W$ value of 20 is assumed based on a DU contaminant, a contamination zone thickness of 1.5 m, and a 15 mrem yr^{-1} remediation goal. Previous investigations of DU contaminants in soils (Rademacher and Hoak 2000) have demonstrated that a 3 x 3 NaI(Tl) is capable of detecting 30 pCi g^{-1} in surface soils from scanning. The plastic scintillator is assumed to have a similar or better capability. Per guidance of Equation 5-3 of MARSSIM (NRC 1997), the combination of an estimated scan MDC of 30 pCi g^{-1} and a $DCGL_W$ of 20 pCi g^{-1}, an appropriate area factor is 1.5. The area factor and their associated areas have impact on the number of soil samples if the spacing between direct measurement locations is

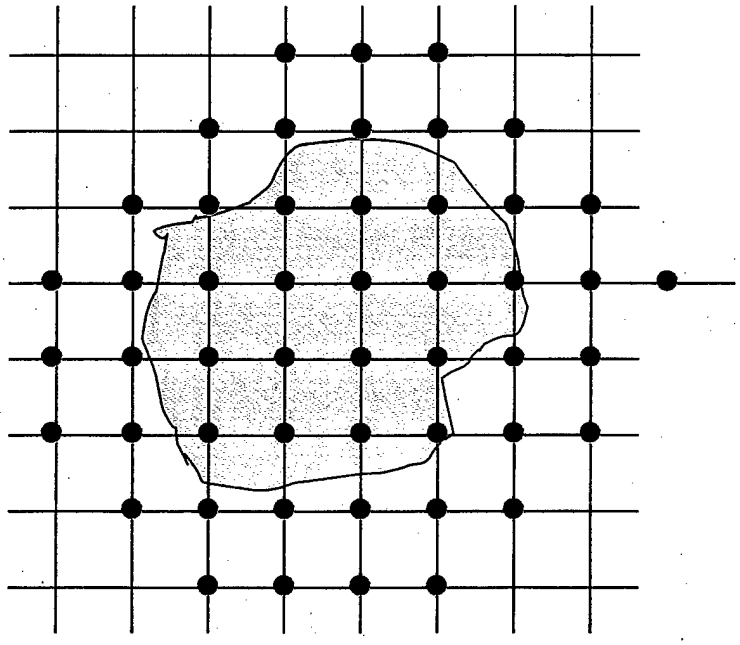
not sufficiently close to detect areas of elevated contamination. MARSSIM (NRC 1997) recommends initially setting the LBGR at 0.5 times the $DCGL_W$.

e) Standard Deviation of Contaminant. The σ value for individual survey units is not known. The results of the scoping survey will provide estimates of these values. For planning purposes, survey point numbers will be estimated, based on a variety of σ values.

f) Data Point Numbers. The number of data points, N, necessary for each survey unit to accomplish the WRS test is calculated using Equation 5-1 of MARSSIM (NRC 1997). For the parameters provided above and σ values of 20, 40, 60, and 80 %, the number of data points are, respectively, 17, 38, 77, and 128. These values are minimums based on the σ and the other factors described above. As noted earlier, additional direct measurements will be collected to address elevated areas within survey units.

4) Fixed In-Situ γ-Measurement Surveys. Scanning γ-measurement instruments have higher MDCs than similar instruments collecting fixed measurements. While scanning instruments are useful in locating "hot spots," fixed in-situ measurements are useful in defining the areas surrounding the "hot spot" where the contamination level is below the scanning MDC. Fixed in-situ γ-measurements also provides the foundation for the final status survey direct measurements. The example of Figure 3 illustrates a grid system of fixed in-situ measurements surrounding a contaminated area. In the example, the red circles represent the measurement above the MDC, while blue are below the MDC. For the illustration, measurements were not collected beyond the point that two measurements were below the MDC. Grid measurements of this type are useful in defining areas of elevated contamination, evaluating the area with respect to risk calculations, evaluating the areal variability in the contamination zone, and providing preliminary waste profiling information.

Figure 3. Grid Pattern Over Contaminated Area.



The integration time for fixed measurements will be sufficient to limit counting uncertainties. For measurement of DU contamination from another survey (Rademacher 2000), 30-second counting periods provided a reasonable balance between counting uncertainty and survey efficiency.

5) Scanning In-Situ Measurements. If the scoping survey indicates that remediation may be likely, then scanning measurements are unlikely to be accomplished in the characterization survey. However, if the results of the scoping survey indicate that remediation may not likely be required, then the characterization survey will likely have additional scanning measurements, as this survey will be a surrogate for a final status survey. In support of a final status survey, scanning measurements are integrated with soil samples in meeting the data quality objectives of demonstrating compliance with the selected remediation criterion. For class 1 areas, MARSSIM (NRC 1997) recommends 100 % scanning coverage, while for class 2 areas 10 – 100 %, and for class 3 areas scanning is based on judgment. Unless remediation is deemed likely from the results of the scoping survey, class 1 survey units will have 100 % scanning coverage. For class 2 survey units, scoping survey-scanning data will be augmented with additional scanning between 10 and 100 %. Twenty-five percent coverage of the class 2 survey units are deemed appropriate for planning purposes. Coverage in excess of this is deemed unnecessary due to the dispersal mechanism of the accident. The fact that metallic fragments were not identified in immediate post accident investigations and the explosion was believed to have completely vaporized the igloo contents, highly localized "hot spot" areas are not highly probable. For the same reasons as described for class 2 areas, designated class 3 areas are not planned for scanning outside of that described in the scoping survey. Locations in the class 2 survey units with scanning measurements above the scanning MDC will be flagged for further investigation.

6) Soil Sampling. Soil sampling is accomplished in characterization studies and final status surveys. Beyond the scoping survey, most additional soil sampling will be accomplished to assess final site status. Limited soil sampling may be planned to supplement scoping survey objectives. For planning purposes, soil samples will be collected from the top 15 cm of soil. Soil samples will be analyzed by γ-spectrocopy, with the total uranium concentration being inferred from analysis of the ^{234}Th activity concentration and the scoping survey α-spectroscopy analysis results. Correlation of soil contaminant concentrations to fixed in-situ measurements can be inferred from results of the scoping survey.

e. Survey Personnel. Table 3 contains a preliminary listing of personnel for accomplishing survey and regulatory oversight.

Table 3. Survey and Regulatory Personnel.

Name	Position	Organization
Major Steven Rademacher, PhD, Certified Health Physicist	AFIERA Technical Lead	AFIERA/SDR, Brooks AFB TX
Major William Pramenko	Health Physicist AF Regulatory POC	Air Force Safety Center, Kirtland AFB NM
Capt Eugene Sheely, PhD	Health Physicist - Survey Leader	AFIERA/SDRH, Brooks AFB TX

f. Instrumentation and Analytical Methods. All portable Air Force field instrumentation will be calibrated at the AFIERA Radiation Instrumentation Calibration Facility. Table 4 contains a summary of instrumentation and laboratory analytical methods.

Table 4. Instrumentation and Analytical Methods.

Measurement Type	Location	Instrumentation	Estimated MDC
Alpha Scintillator	Investigation Area	Ludlum Model 3	10 dpm cm^{-2}
In-situ gamma (fixed)	Investigation Area – 10 cm above surface	3 x 3 NaI (Tl) w/ Ludlum 2221	6.4 pCi g^{-1} (DU)
In-situ gamma (scanning)	Investigation Area – 30 cm above surface	15 cm x 120 cm Plastic Scintillator	30 pCi g^{-1} (DU)*
Surface soil samples	Surface samples – Variable Depths	Laboratory Gamma Spectroscopy – U-238 U-235	1.0 pCi g^{-1} 0.1 pCi g^{-1}

* Inferred From 3 x 3 NaI(Tl) Ability (Rademacher and Hoak 2000)

7. Quality Assurance/Quality Control

a. General. Quality assurance (QA) refers to the planning, implementation, and oversight conducted to ensure the data produced are useful for decision making. QA measures that will be implemented include chain of custody controls and documentation, review of data collection procedures and documentation, and review of laboratory results. Quality Control (QC) is the system or series of activities conducted to control and measure the validity and completeness of the data produced. QC measures that will be implemented include function and radiation response checks (beginning and end of each workday) for radiation detection instrumentation, and use of redundant radiation detector systems (duplicate measurements). QC measures for soil includes collection of one set of QC samples for every 10 samples of a given type (soil surface, subsurface) collected. The set of QC samples consists of the following items:

1) Collocated Samples. Collocated samples are samples collected adjacent to the routine field sample to determine local variability of the radionuclide concentrations. Typically, collocated samples are collected about one-quarter to one-meter away from the selected sample location. Analytical results from collocated samples can be used to assess site variation, but only in the immediate sampling area. Most of the collocated sample collections will be accomplished primarily in the scoping survey.

2) Field Replicates. Field replicates are samples obtained from one location, homogenized, divided into separate containers, and treated as separate samples throughout the remaining sample handling and analytical processes. These samples are used to assess uncertainties associated with sample heterogeneity, sample methodology and analytical procedures. One-tenth of the scoping and final status survey soil samples will have field replicates.

b. Private Laboratory Samples. The purpose of splitting a fraction of samples for intercomparison with an outside independent laboratory is to lend credibility to the analytical data of AFIERA's laboratory. One-tenth of the final-status soil samples will be split in the field, with one half being retained by AFIERA for analysis, and the other half being sent to Duke Engineering Services for gamma spectroscopy analysis.

c. Data Analysis of Quality Control Samples. Quality control samples will be compared statistically to a paired sample and a collocated sample. For paired samples, relative percent difference will be calculated as follows:

$$\mathrm{RPD} = \frac{2(M_1 - M_2)}{(M_1 - M_2)} \times 100,$$

where M_1 and M_2 are the respective sample activity concentrations. For sample groups (i.e. $n > 2$), percent coefficient of variation (% CV) will be calculated as follows:

$$\%\,\mathrm{CV} = \frac{\mu}{\sigma} \times 100,$$

where μ and σ respectively are the mean and standard deviation. These indices will be used to estimate the confidence in the estimation of the final site status.

8. Health and Safety.

a. Radiation Exposure. The radiological risk presented to the work crew is small based on the activity concentration level of depleted uranium in soils from the AFIERA pilot scoping survey. The areas sampled in this survey had elevated γ-radiation levels, with the anticipation that other areas will not have significantly higher levels. Personnel will wear disposable gloves during collection of soil samples for the purpose of preventing cross-contamination. All survey personnel and equipment leaving the area will be frisked with an alpha scintillation detector. Eating, smoking, and drinking will be prohibited within the investigation area. Personal protective equipment (PPE) like air-purifying respirators and anti-contamination clothing will be available if unsuspected radiation hazards are uncovered. Based on the characterization survey, this appears unlikely. Modified level D (steel toe boots, long sleeves, and gloves) will be utilized initially. Should unanticipated conditions arise, higher levels of PPE and monitoring will be implemented at the discretion of the team chief.

b. Physical Hazards.

1) Terrain. The terrain in the investigation area is generally flat with irregular features that present tripping and ankle injury hazards. Personnel will be required to wear high-top leather boots.

2) Heat Stress. All team members will be briefed on the signs and symptoms of heat stress. Drinking water and sunscreen will be available at the vehicle parking area. Work/rest regimes will be implemented if conditions are conducive to heat stress.

3) Wildlife/Insects. The remediation area may be home to biting insects, ticks, snakes, and rodents. Personnel will be wearing military battle dress uniforms that have been designed with protective features against insect bites. Insect repellent will be available to team members.

c. Adverse Weather Conditions. Adverse weather conditions will suspend site operations because of the risks for personnel injuries and potential for dispersal of contaminated soils from high winds.

d. Medical Emergencies. If a medical emergency arises, the base fire department will be contacted at 911 or via the base radio net.

9. References.

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Nuclear Regulatory Commission (NRC), Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), NUREG-1575, December 1997.

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Yu, C.; Zidan, A.J.; Cheng, J.J.; Yuan, Y.C.; Jones, L.G.; LePoire, D.J.; Wang, J.J.; Loureiro, C.O.; Gnanaprgusan, E.; Faillace, E.; Wallo III, A.; Williams, W.A.; Peterson, H.; Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Argonne National Laboratory, Argonne, IL, Report Number ANL/EAD/LD-2, 1993.

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Appendix A

Site Maps of Lackland Training Annex (Formerly Medina Base) and May 2000 Scoping Survey Soil Sampling Locations

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Figure A-1. Lackland Training Annex and Vicinity.

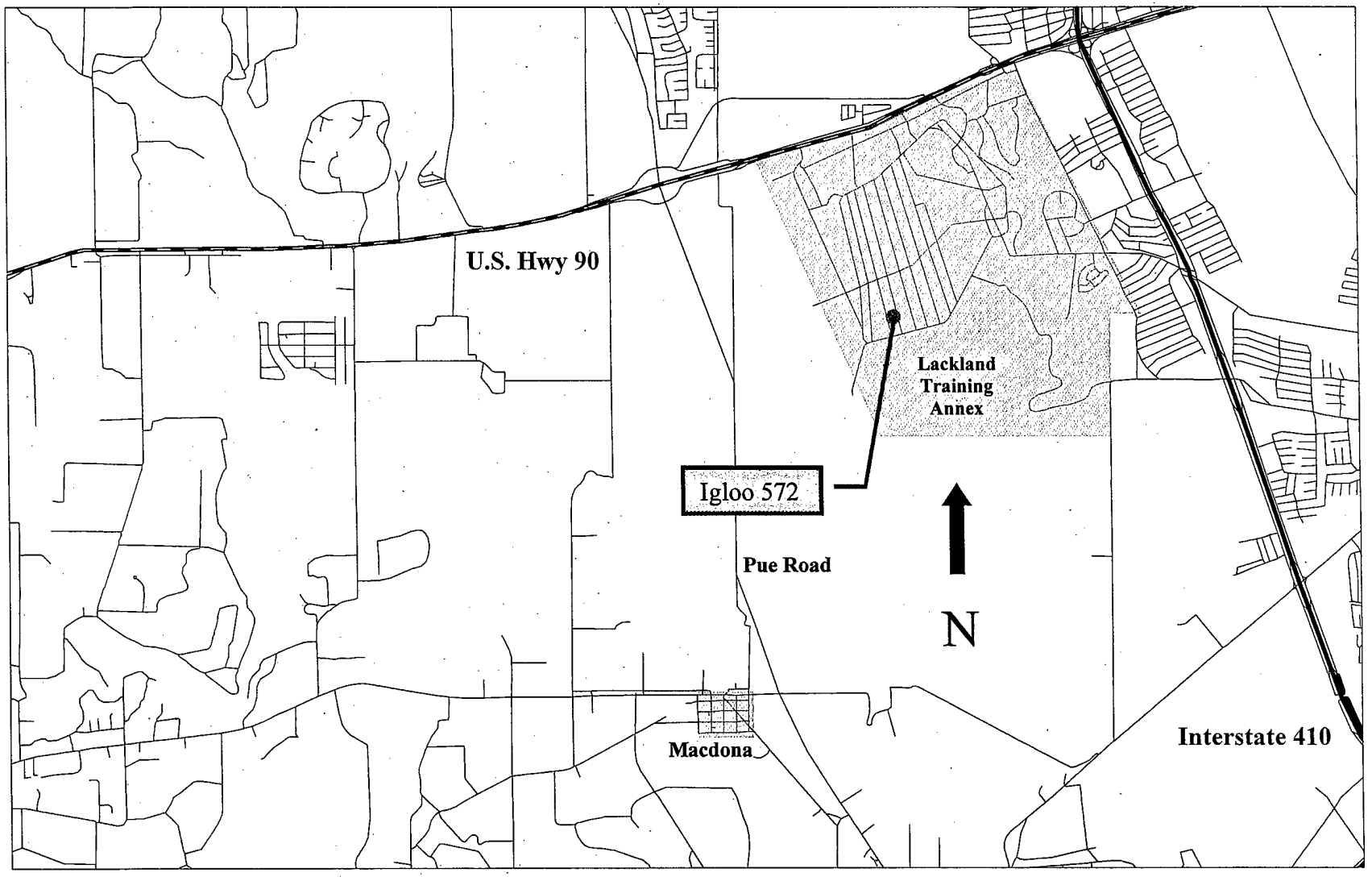


Figure A-2. Lackland Training Annex.

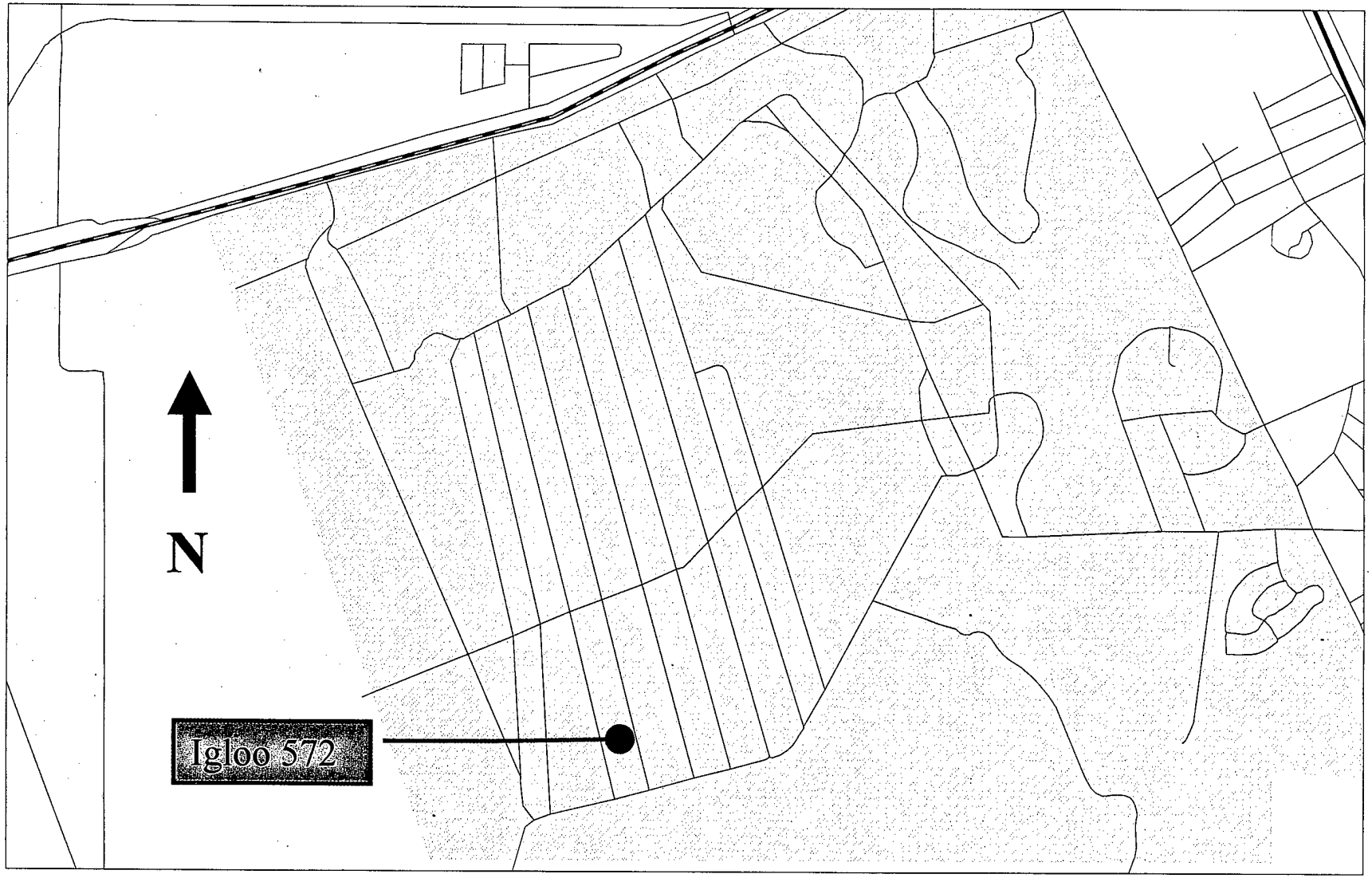
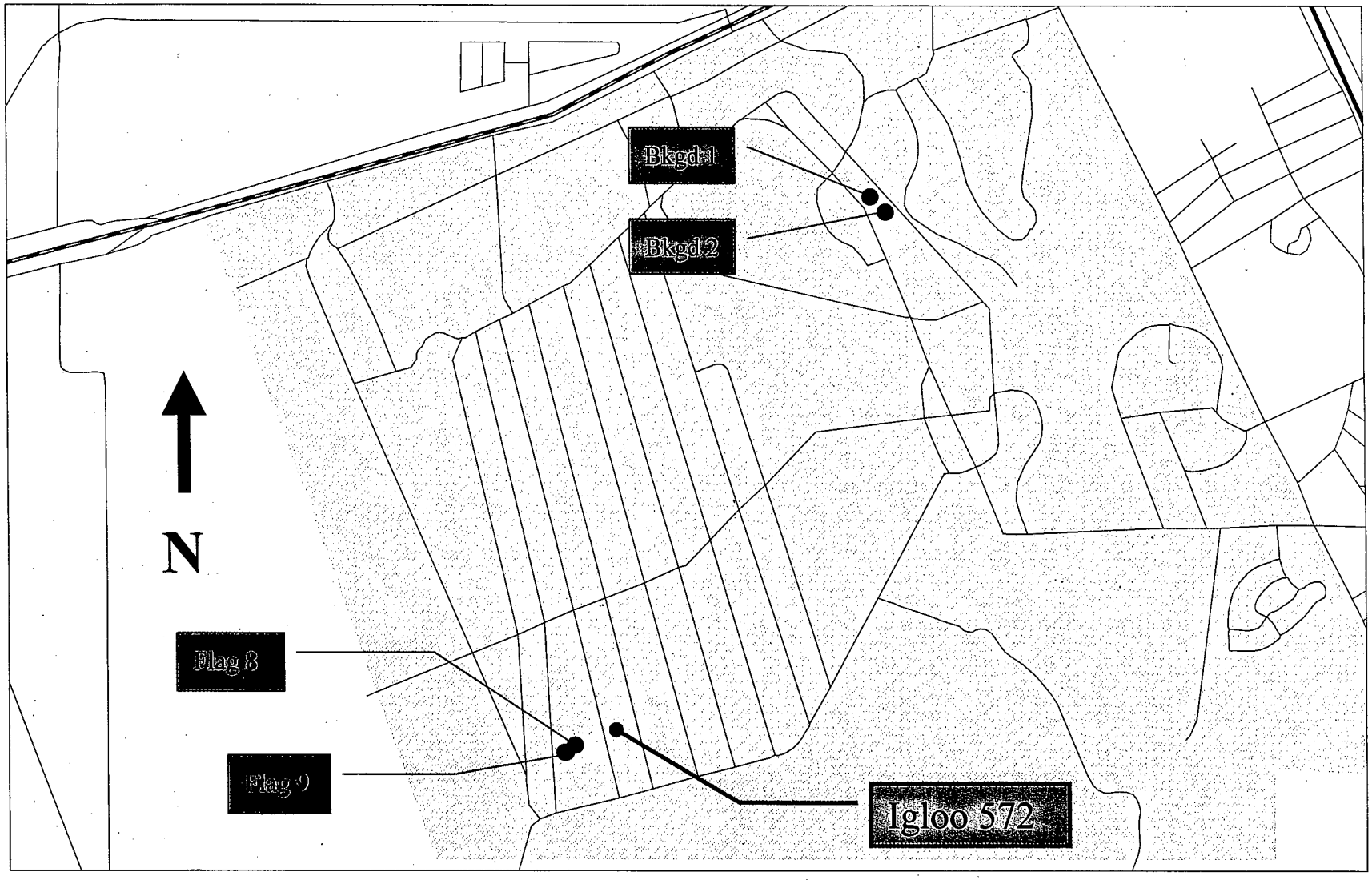


Figure A-3. May 2000 AFIERA Scoping Survey Soil Sampling Locations.



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Appendix B

Historical Site Investigation Data
(Various Sources)

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Figure B-1. Aeroradioactivity Map of Medina Base.
[Figure 1 of EG&G Report: Special Aerial Radiometric Survey - Medina Base and Vicinity (EG&G 1963)].

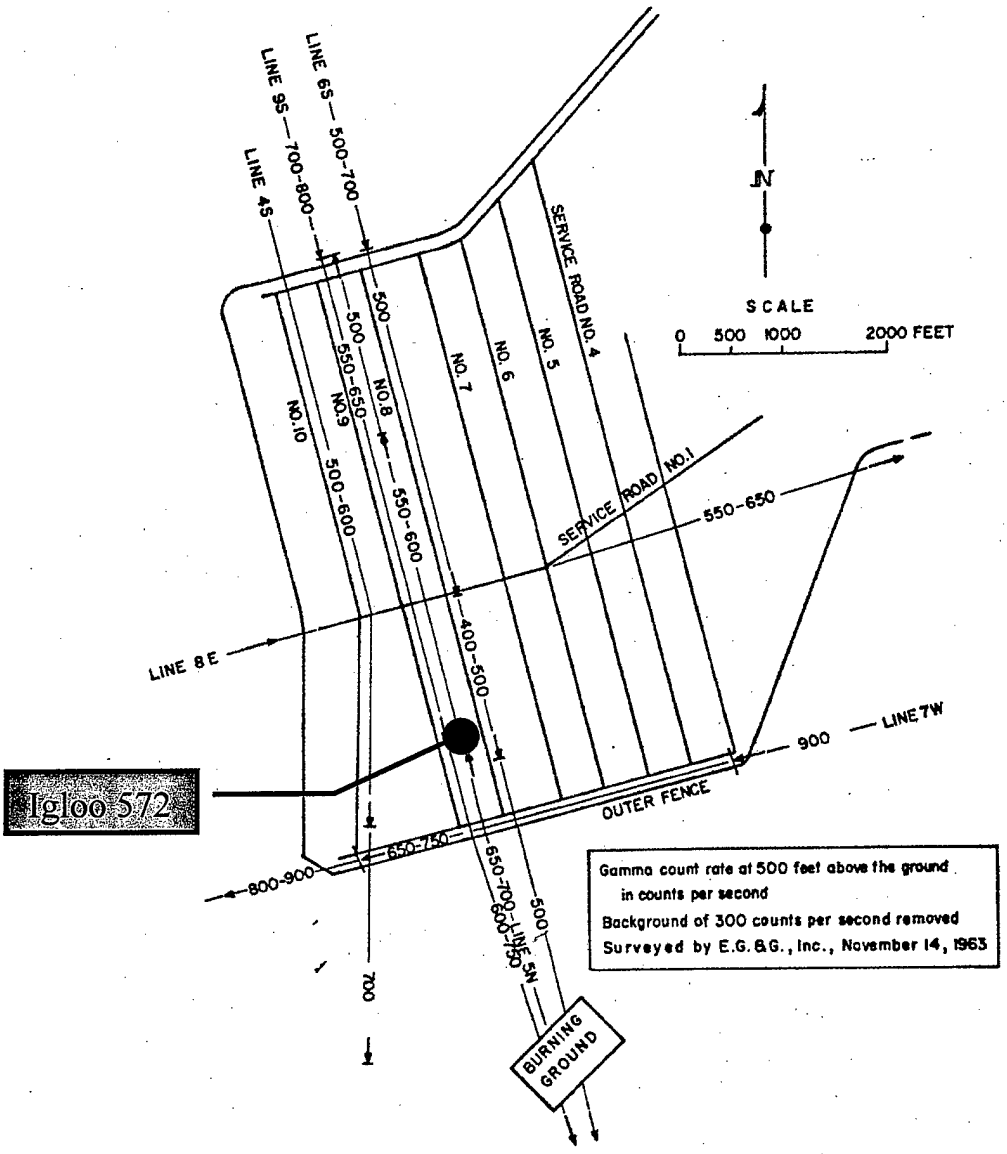


Figure B-2. Aeroradioactivity Map of Medina Base and Vicinity. [Figure 2 of EG&G Report: Special Aerial Radiometric Survey - Medina Base and Vicinity (EG&G 1963)].

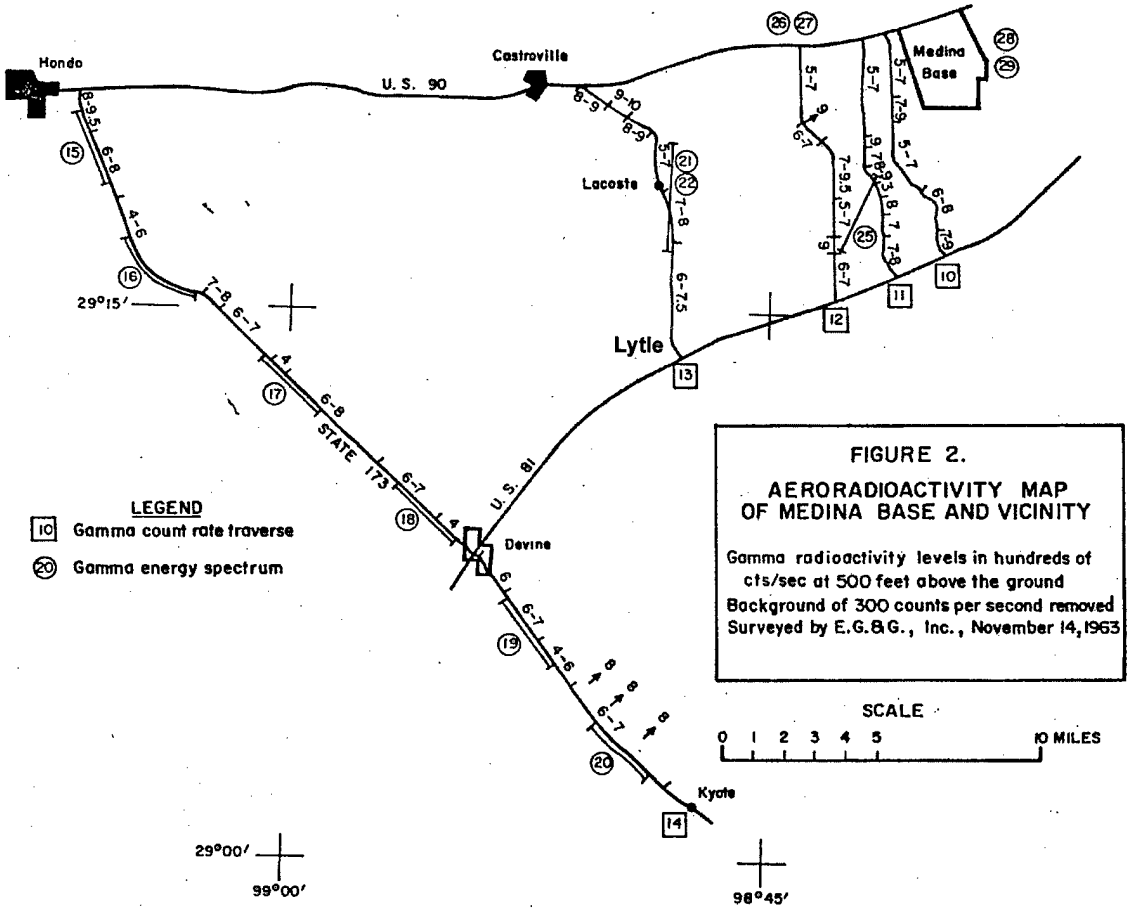


Table B-1. Atomic Energy Commission On-Site Soil Sampling Analysis Results [Immediate Vicinity of Point of the Accident] (Kingsley 1963).

Sample Number	Coordinate Locations		Net ^{238}U in Soil*	
	(East)	(West)	$\mu g\ g^{-1}$	$pCi\ g^{-1}$
1	2102600	557600	780	260
2	2102600	557200	1112	370
3	2102600	556800	1875	620
4	2101100	556500	2398	790
5	2103000	557300	284	94
6	2103800	557400	242	80
7	2103900	557000	823	270
8	2104000	556700	706	230
9	2104300	557400	7	2.3
10	2104400	557000	336	110
11	2103400	556900	1188	390
12	2102000	558000	ND	ND
13	2102000	557000	4	1.3
14	2102000	556000	26	8.6
15	2103000	556000	5	1.7
16	2104000	556000	65	21
17	2101000	558200	ND	ND
18	2101300	557200	1	0.3
19	2101500	556100	2	0.7

* Assumed Background of 2 $\mu g\ g^{-1}$ ^{238}U
ND = None Detected

Table B-2. Atomic Energy Commission Off-Site Environmental Sampling Analysis Results (Kingsley 1963).

Sample Number	Description of Sample	Location of Sample Collection	Net ^{238}U	
			Soil $\mu g\ g^{-1}$	Water $\mu g/70$ ml
2	Pea Gravel/Fine Dirt	5 miles West of Site on Hwy 90	ND	NA
3	Fine Dirt	0.3 miles South of Castroville	ND	NA
5	Sand & Dirt	Castroville	ND	NA
6	Fine Dirt	½-way between Hwy 90 and Riomedina on FM 471	ND	NA
9	Pea Gravel and Fine Sand	Riomedina	ND	NA
10	Fine Dirt	10 miles South of Hwy 90 on Melchor Rd South	ND	NA
12	Gravel, Sand, Dirt	Lacoste	ND	NA
15	Gravel & Dirt	5 miles South of Lacoste	ND	NA
16	Fine Sand & Dirt	Lytle	ND	NA
1	Water	5 miles West of Site on Hwy 90	NA	ND
4	Water	Castroville	NA	ND
7	Water	½-way between Hwy 90 and Riomedina on FM 471	NA	ND
8	Water	Riomedina	NA	ND
11	Water	10 miles South of Hwy 90 on Melchor Rd South	NA	ND
13	Water	Lacoste	NA	ND
14	Water	5 miles South of Lacoste	NA	ND
17	Water	Lytle	NA	ND

NA = Not Applicable
ND = Not Detected

Table B-3. Texas State Dept. of Health Environmental Sampling Results [Sample Analysis Performed by the Southeastern Radiological Health Laboratory, U.S. Public Health Service, Montgomery, Alabama] (Barden 1963).

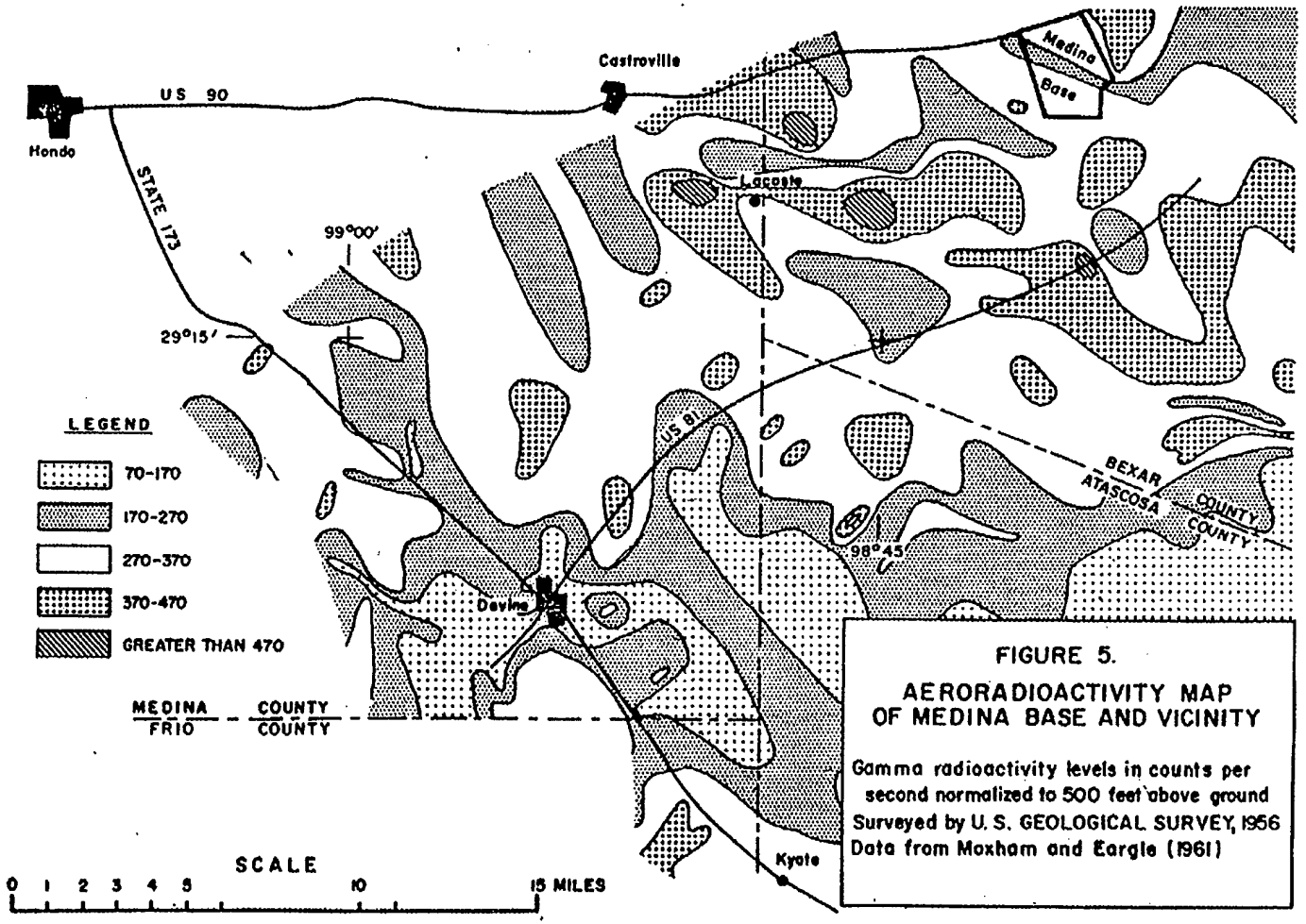
SERHL Code Number	Description of Sample	Location of Sample Collection	Alpha* Activity Concentration (pCi kg^{-1})	Gamma Isotopes Indentified
SpV-5	Rutabega Leaves	Station 4, FM-471	60 ± 3	TB
SpV-6	Johnson Grass	Station 1, Pue Rd.	80 ± 46	TB
SpV-7	Grass	Castroville	10 ± 36	TB
SpV-9	Vegetation	Route 9, Masterson Rd.	780 ± 70	TB
SpV-11	Vegetation	2 miles S.E. of Castroville	100 ± 32	TB
SpV-13	Vegetation	1.5 miles North of Lytle	50 ± 26	TB
SpV-15	Vegetation	2 miles West of Macdona	20 ± 29	TB
SpS-4	Soil	Station 2, Pue Rd.	19600 ± 3600	TB
SpS-8	Soil	Station 1, Pue Rd.	8400 ± 2600	TB
SpS-10	Soil	Route 9, Masterson Rd.	34200 ± 3800	TB
SpS-12	Soil	2 miles S.E. of Castroville	30500 ± 4000	TB
SpS-14	Soil	1.5 miles North of Lytle	25200 ± 3400	TB
SpS-16	Soil	2 miles West of Macdona	51800 ± 5700	TB

SERHL Code Number	Description of Sample	Location of Sample Collection	Alpha Activity Concentration (pCi l^{-1})		Gamma Isotopes Indentified
			Suspended Solids	Dissolved Solids	
SpW-577	Water	Station 1, Pue Rd.	< 0.1	0.4 ± 0.3	NS
SpW-578	Water	Station 2, Pue Rd.	0.30 ± 0.08	0.3 ± 0.6	NS
SpW-579	Water	Station 3, Hwy. 90	0.40 ± 0.09	0.2 ± 0.4	TB
SpW-580	Water	1.5 miles North of Lytle	0.50 ± 0.11	1.2 ± 0.9	NS
SpW-581	Water	2 miles West of Macdona	0.60 ± 0.11	1.2 ± 0.6	NS

* Samples were ashed as part of the analysis procedure

Uncertainty values are at the one-σ level

Figure B-3. Aeroradioactivity Map of Medina Base and Vicinity. [Figure 5 of EG&G Report: Special Aerial Radiometric Survey - Medina Base and Vicinity (EG&G 1963)].



Appendix C

Uranium Decay Series

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Table C-1. U-238 Decay Series.

Isotope	Half-life	Radiation	Energy (MeV)	Percent Yield
^{238}U	4.5×10^9 y	α	4.2	75
			4.15	23
		γ	0.0496	0.07
^{234}Th	24 d	β	0.192	65
			0.100	35
		γ	0.092	4
^{234m}Pa	1.2 min	β	2.29	98
			1.53	<1
			1.25	<1
		γ	0.39	0.13
			0.817	4
^{234}U	2.5×10^5 y	α	4.77	72
			4.72	28
		γ	0.093	5

Table C-2. U-235 Decay Series.

Isotope	Half-life	Radiation	Energy (MeV)	Percent Yield
^{235}U	7.1×10^8 y	α	4.32	3
			4.21	5.7
			4.58	8
			4.5	1.2
			4.4	57
			4.37	18
		γ	0.110	2.5
			0.143	11
			0.163	5
			0.185	54
			0.205	5
^{231}Th	25.64 h	β	0.302	52
			0.218	20
			0.138	22
		γ	0.026	2
			0.085	10

Appendix D

Uranium Isotopic Distributions

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Figure D-1. U-238/U-234 and U-238/U-235 Ratio for Various Concentrations of Depleted Uranium (DU) Contaminant in Presence of 1 pCi/g Background Natural Uranium.

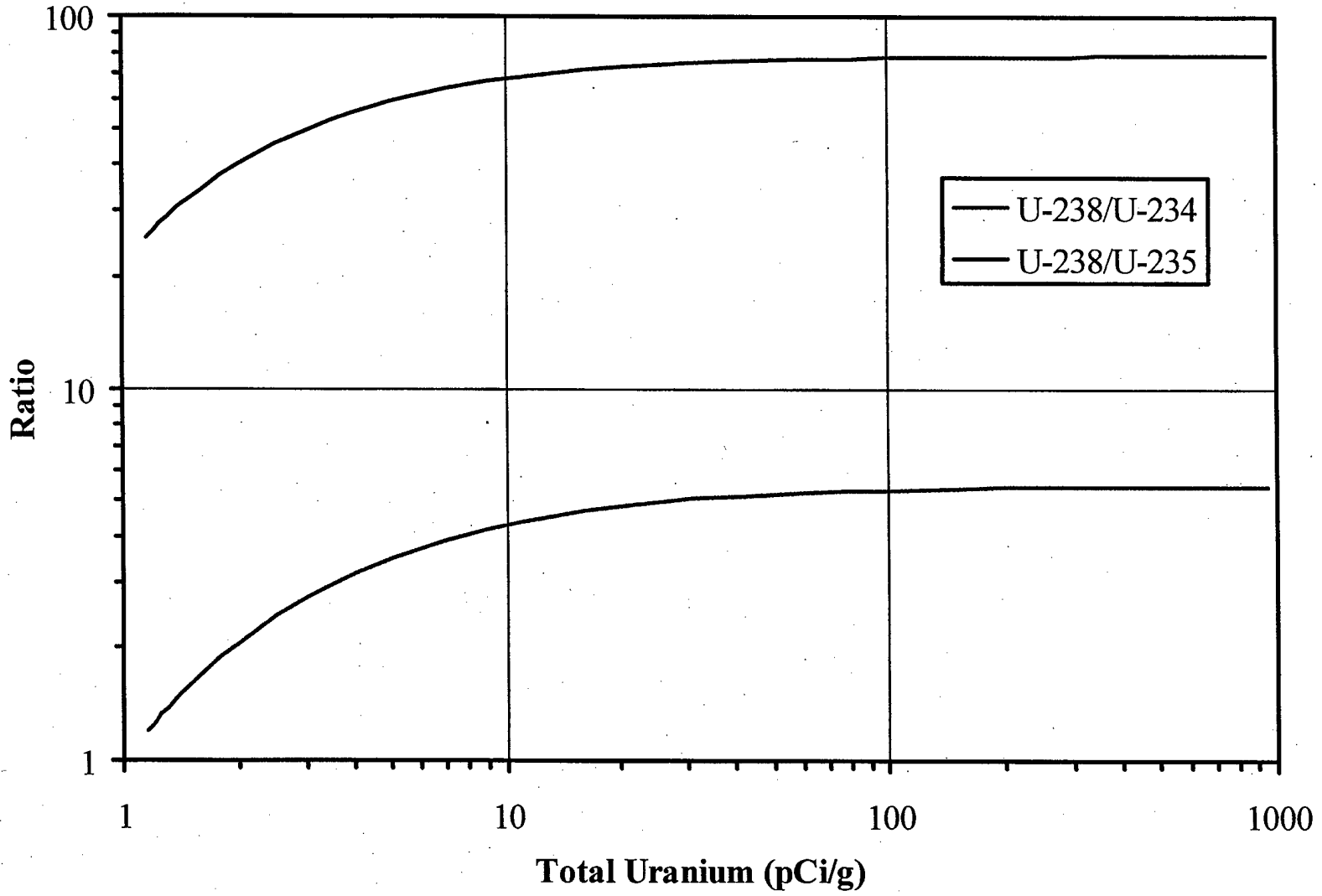


Figure D-2. U-238/U-234 Ratio for Various Mixtures of a Depleted Uranium (DU) and Tuballoy (TU) Contaminant in Presence of 1 pCi/g Background Natural Uranium.

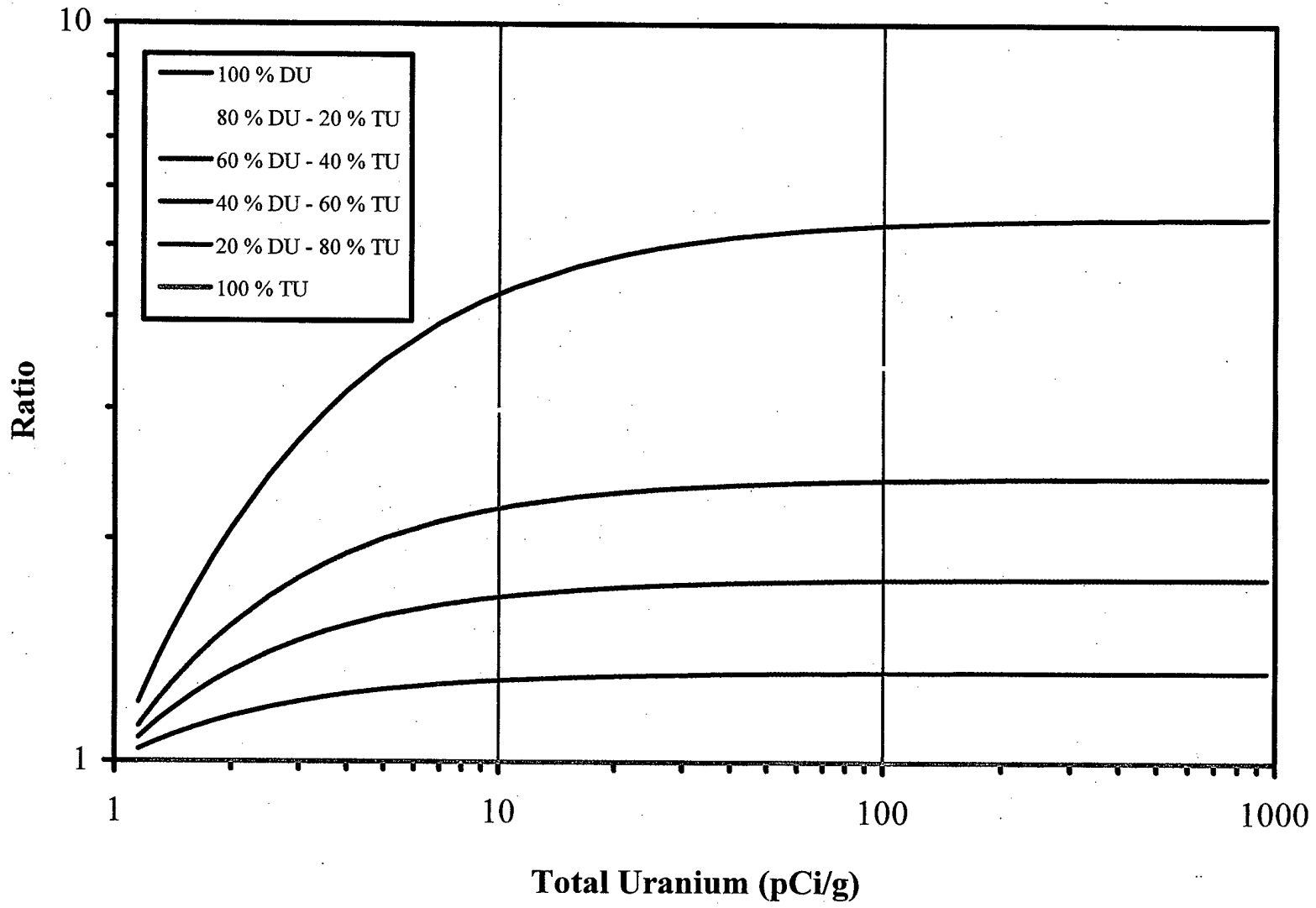
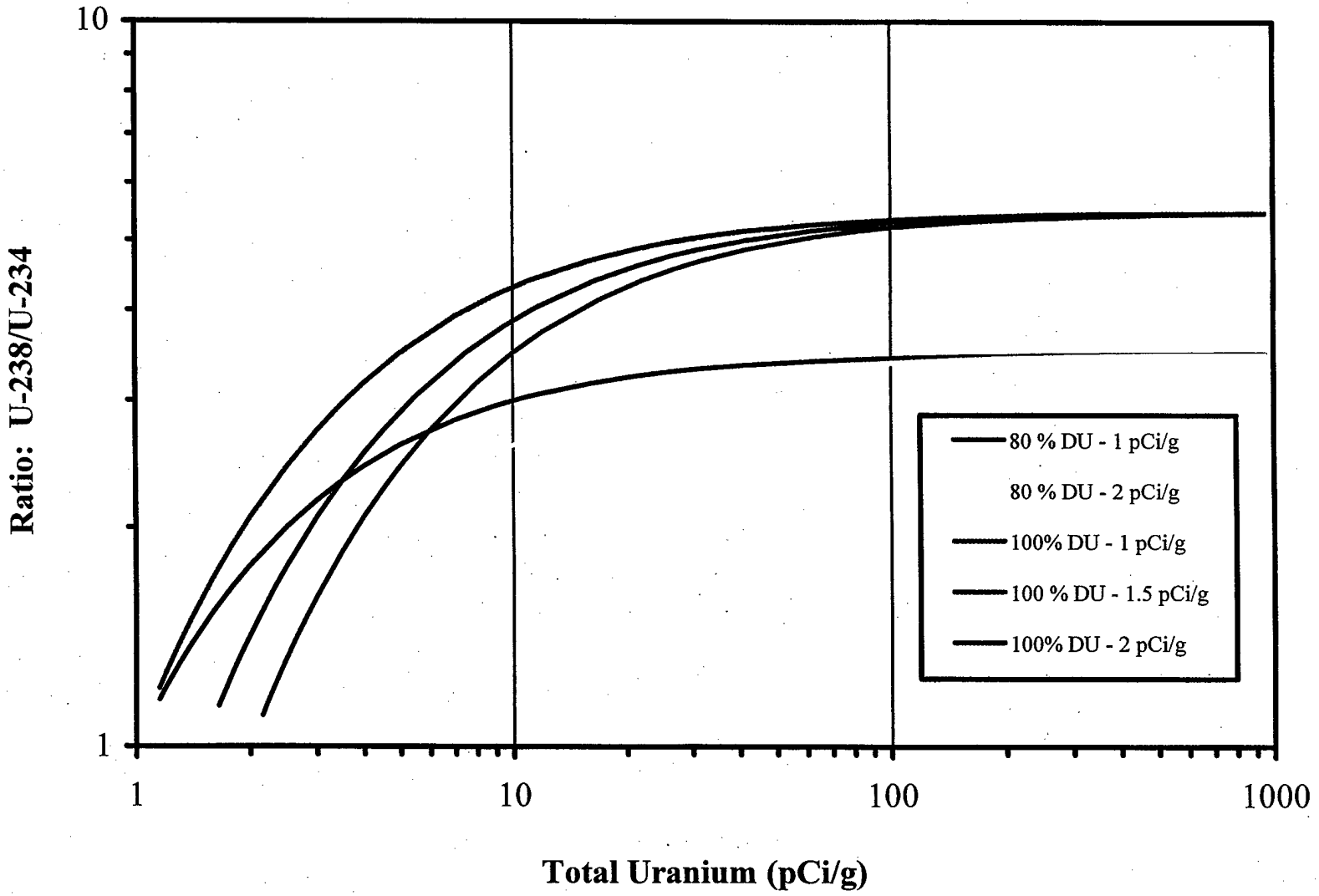


Figure D-3. U-238/U-234 Ratio for Two Mixtures of a Depleted Uranium (DU) and Tuballoy (TU) Contaminant in Presence of Varying Natural Uranium Background.



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Appendix E

RESRAD Calculations

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Table E. RESRAD Calculations.

Contamination		Uranium Contaminant	Activity Concentration (pCi/g)	Dose Equivalent Rates at Specified Times Post Deposition			DCGL for 15 mrem per year for Max Dose Time	Area Factor for Dose Max Time
Zone Area (square-meters)	Zone Thickness (meters)			(t = 0) mrem/yr	(t = max) mrem/yr	Time @ Max (yr)		
10,000	0.15	DU	1	0.095	0.095	0	158	1
10,000	0.3	DU	1	0.11	0.16	1000	94	1
10,000	0.5	DU	1	0.12	0.27	1000	56	1
10,000	1	DU	1	0.15	0.53	1000	28	1
10,000	1.5	DU	1	0.15	0.78	1000	19	1
10,000	2	DU	1	0.15	0.99	1000	15	1
10,000	2	TU	1	1.3	1.3	0	12	1
10,000	0.15	TU	1	0.076	0.076	0	197	1
[illegible]	0.15	DU	1	0.095	0.095	0	158	1
[illegible]	0.15	DU	1	0.086	0.086	0	175	1.1
[illegible]	0.15	DU	1	0.060	0.060	0	251	1.6
10,000	1	DU	1	0.15	0.53	1000	28	1
1,000	1	DU	1	0.14	0.51	1000	29	1.0
300	1	DU	1	0.089	0.45	672	33	1.1
100	1	DU	1	0.070	0.30	529	50	1.8
10,000	2	DU	1	0.15	0.99	1000	15	1
1,000	2	DU	1	0.14	0.96	1000	16	1.0
300	2	DU	1	0.089	0.72	672	21	1.4
100	2	DU	1	0.070	0.42	530	36	2.4

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